ENVIRONMENTAL ENTREPRENEURSHIP:
A PRACTICAL LAB-TO-MARKET APPROACH

by

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Executive Summary

Environmental entrepreneurship as a field is moving from the background of entrepreneurship to the foreground, as larger and larger environmental problems are seen as opportunities for entrepreneurial activity. However, environmental technologies emerging from laboratories have longer research periods, may take longer to produce products, and may not fit into the traditional startup pathways that venture capital (VC) firms look for out of universities.

Building upon existing literature, a framework for analysis and a path towards the marketplace were created using Dr. Jesko von Windheim's Lab-to-Market Framework (von Windheim & Myers, 2014) and Four Forces Analysis paper (von Windheim & Doyle, 2013).

Six environmental entrepreneurial opportunities were selected from Duke and affiliates: macroalgae biomass harvesting, lighthouse rentals, a billfish lure invisible to sea turtles, mammalian cell lifespan extension, increased drought resistance in flowering plants, and Zylon – a method for producing renewable nylon. These opportunities were analyzed with a modified opportunity analysis in line with the framework developed, and three were selected for further investigation.

The three opportunities selected (Zylon, the billfish lure invisible to sea turtles, and increased drought resistance in flowering plants) were further analyzed beyond the initial opportunity analysis. Zylon was chosen as the best candidate for development as a start-up, and a four forces analysis performed to select the best method for moving forward.

A business case is presented for Zylon, based on work done in the *Entrepreneurial Experience* course and materials created for the Duke Start-Up Challenge.

Recommendations for next steps for Zylon are provided based on these experiences and advice from judges, industry consultants, and advisors: demonstrate the improved economics of Zylon; seek out niche markets where green nylon will be prized; and move Zylon out of the university.

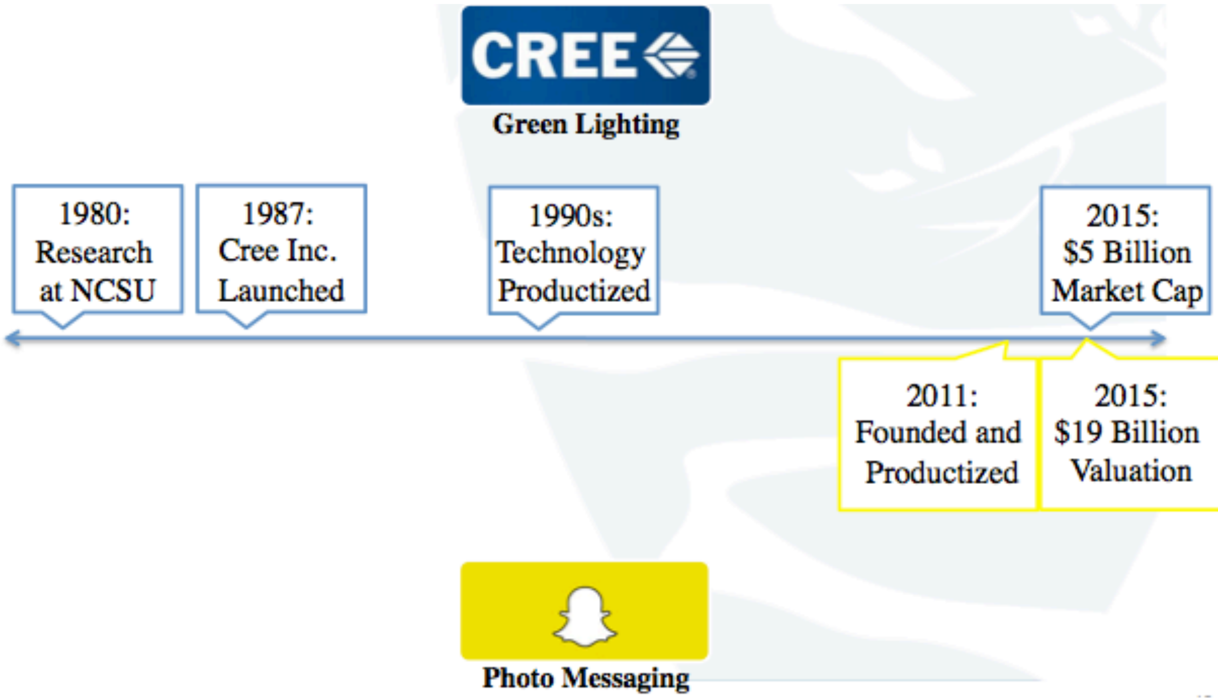
Overview

Environmental entrepreneurship is a growing field, and universities are looking to take a greater role in teaching entrepreneurship and participating in the process of launching startups. Research and information exist around environmental entrepreneurship, as well as significant experience for universities giving birth to startups. Programs such as the National Science Foundation's (NSF) Innovation Corps (I-Corps) exist solely to help bring promising technologies out of university laboratories.

However, lab technologies residing in universities may need longer to finish research and development than startups currently funded by VCs, and the environmental field has a long feedback loop. The effects of a new technology may not be felt for years or even decades.

An example of environmentally beneficial technology development that made it to the marketplace is Cree Inc., which is currently one of the world leaders in LED lighting technology. Cree Inc. was founded by three researchers from North Carolina State University, building on 10 patents and years of research. It still took them two years to release their first product, and decades to become the large company that they are today ("Cree Inc. History," n.d.). Figure 1 shows Cree Inc. in comparison to another company, Snapchat, which was developed in 5 months by a Stanford drop-out (Colao, 2012).

Figure 1 - Laboratory Technology Development vs App Development



Dr. Jesko von Windheim has codified the lab-to-market approach as a step-by-step model for bringing forth research from universities into the startup world in his paper "A lab-to-market roadmap for early-stage entrepreneurship" (von Windheim & Myers, 2014). Using this framework, I sought to analyze, evaluate, and select a technology from Duke University or an affiliate. The resulting analysis and selection formed the basis to launch a startup: Zylon.

This project serves two primary functions: determine the economic and environmental feasibility of environmental entrepreneurship opportunities and look to position one of the ideas for startup, as well as set the foundation for future Master of Environmental Management students to create startups based on strategic evaluation of environmental ideas and intellectual property (IP).

Methods

A review of relevant literature focused on two main areas: lab-to-market university entrepreneurship and environmental entrepreneurship. The intersection of these two spaces is university-generated environmental entrepreneurship, and a combined search into both fields should yield sufficient material for further analysis.

New opportunities based on environmental technology were discovered at Duke University through a combination of IP research at the Duke Office of Licensing and Ventures (OLV) and also through personal interviews.

Figure 2 - Opportunity Analysis Metrics

Team: Are team members experts in their fields?
Market: Is there a large enough market?
Technology: Is the technology unique? Patentable?
Customers: Are there paying customers available?
Execution: Can the team successfully execute on this opportunity?

First order reviews were performed on each opportunity identified using a basic opportunity analysis. Each opportunity or technology is given a cumulative grade (out of 25 available points) based on five metrics (See Table 1 for a scoring breakdown and Figure 2 for a breakdown of the metrics). Information to answer the questions posed by each criterion were provided by journal and business articles searches, personal interviews, and market analysis.

Table 1 - Opportunity Analysis Scoring

	Bad		Good		Great	
Team	0	1	2	3	4	5
Market	0	1	2	3	4	5
Technology	0	1	2	3	4	5
Customers	0	1	2	3	4	5
Execution	0	1	2	3	4	5

Additionally, a Four Forces method for environmental decision making, based on Porter's five-forces methodology, was utilized for a deeper analysis of the final opportunity (von Windheim & Doyle, 2013).

Of the opportunities analyzed, Zylon displayed the highest potential for success as a startup, resulting in the application of the lab-to-market framework to Zylon in a two-phase approach:

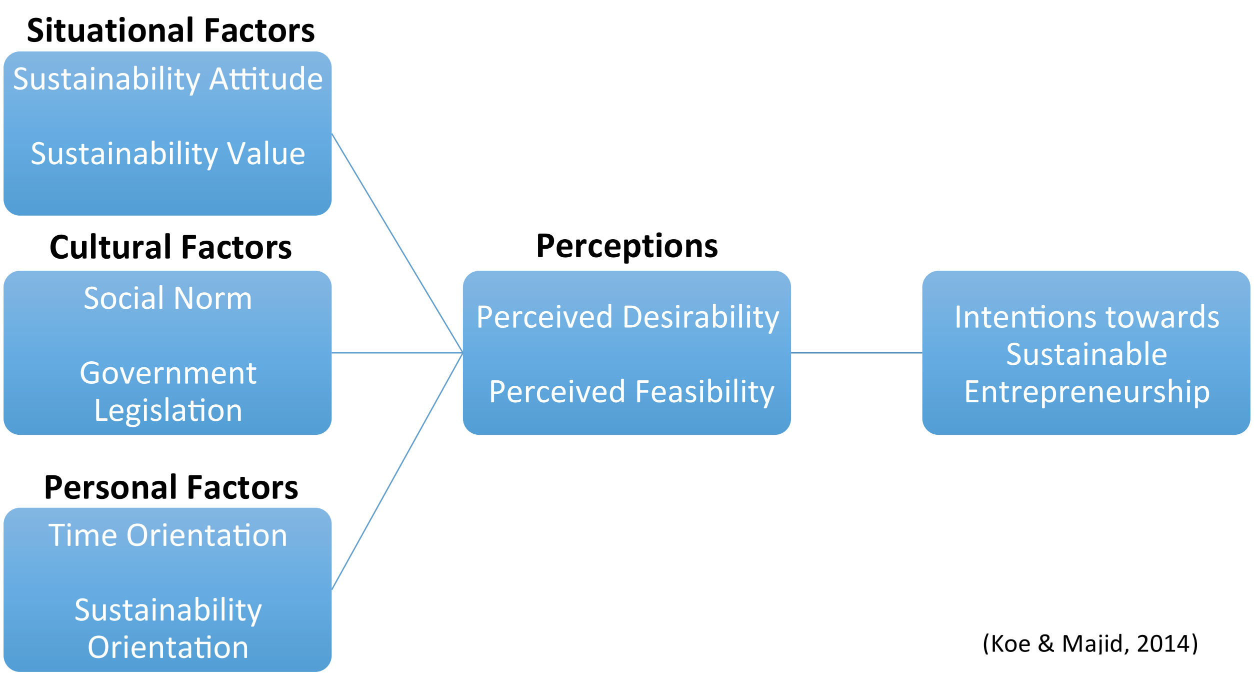
1. I led a team in Dr. von Windheim's *Entrepreneurial Experience* course, which produced the business documentation, execution plan, and pitch materials necessary for a startup.
2. Based off of the materials created in the *Entrepreneurial Experience* course, I am leading a team in the Duke Startup Challenge to launch a company based on the Zylon technology.

Introduction

The relevant literature focused mainly on three aspects of sustainable entrepreneurship: 1.) differentiation between "normal" entrepreneurship and environmental or sustainable entrepreneurship, 2.) environmental entrepreneurship as a facet of traditional entrepreneurship that takes advantage of market failures, or 3.) how and why environmental startups can be successful.

The studies that seek to differentiate between "normal" entrepreneurship and environmental or sustainable entrepreneurship portray environmental entrepreneurs as conflicted or struggling against traditional forces. Koe and Majid (2014) try to predict the "intention to embark on" environmental and sustainable entrepreneurial endeavors, especially within companies. The model created suggests that values and belief in the need for environmental change dictates the successful adoption of environmental entrepreneurial programs.

Figure 3 - Model for Predicting Intention towards Sustainable Entrepreneurship



Chapple (2010) and Linnanen (2002), however, focus on the need to create new markets. Where new markets for environmental services and products are successfully established, they find environmental entrepreneurs to be more successful. This applies not just to selling into the market, but in raising funds for their ventures as well.

The same studies portray environmental entrepreneurs as facets or subgroups of traditional entrepreneurship, focusing on a specific set of market failures. Koe and Majid (2014), Dean (2007), and Cohen (2007) see environmental entrepreneurs as entrepreneurs who are opportunistically looking to address market failures created by the traditional entrepreneurship and business model. That many environmental startups have the additional goal of improving environmental and social conditions is secondary to their analysis of startups: the goal of any startup is to generate profits at a level that is necessary for the long-term survival of the company. Environmental opportunities simply represent new opportunities and new markets.

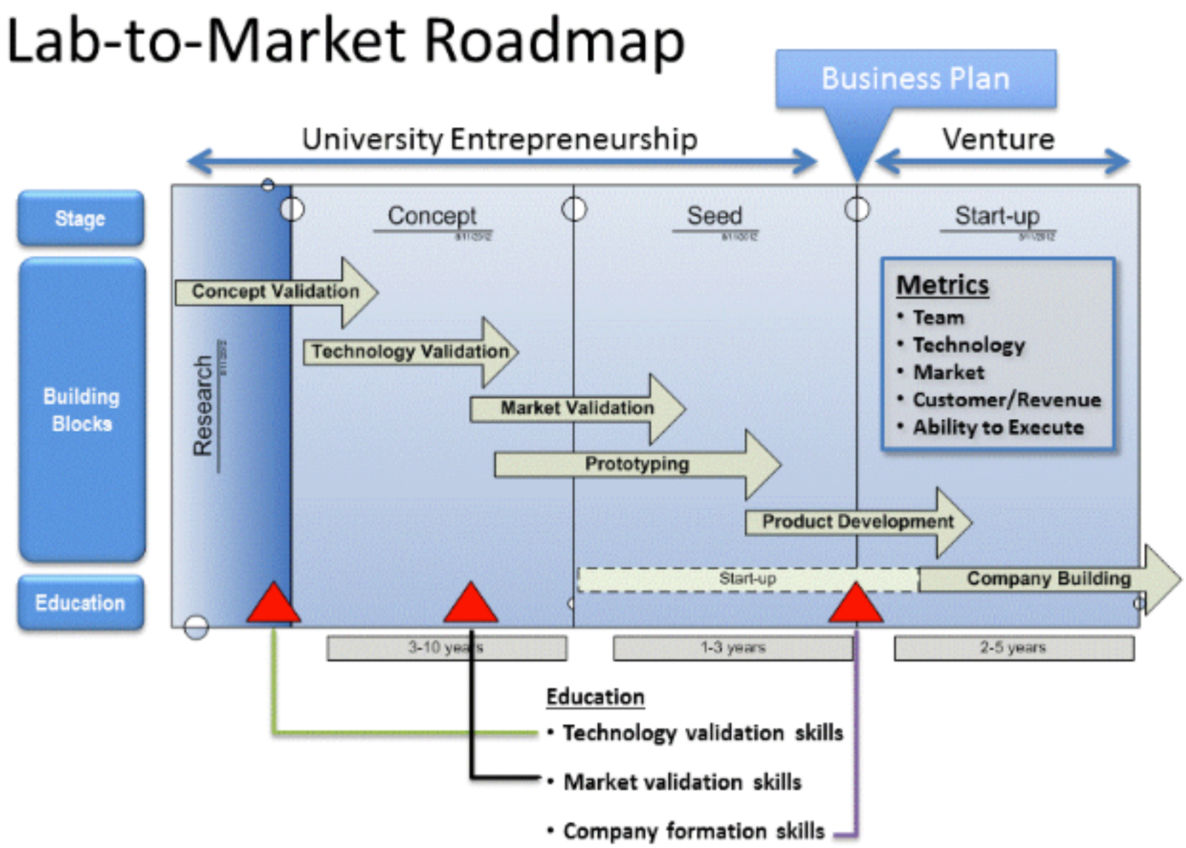
Parrish (2010) and Chapple (2010) both additionally look at how environmental startups can be successful. Parrish focuses on the disparate goals and challenges that environmental entrepreneurs face, and determines that organizational design is what leads environmental entrepreneurs to be successful. It is only through successfully addressing conflicting stakeholders, goals, and market needs in the design of the startup itself that allows for success and the opportunity to thrive. Chapple, coming from a regional development standpoint, looks at government support and infrastructure development as key to environmental entrepreneurship. Regions and government must make themselves amenable to the creation of environmental markets by providing support for environmental endeavors that may not exist elsewhere.

The two relevant studies that don't fit this three-tiered framework are Nadim and Singh's "A System's View of Sustainable Entrepreneurship Education" (2011), and Linnanen's "An Insider's Experiences with Environmental Entrepreneurship" (2002). Nadim and Singh are critical of the segmentation proposed above. Instead of segmenting entrepreneurship education into entrepreneurship training and sustainability training, they suggest that a more seamless integration of environmental entrepreneurship and traditional entrepreneurship into a single environmental entrepreneurship education will strengthen both sustainability and entrepreneurship.

Linnanen (2002) offers the most in-depth analysis of environmental entrepreneurship, and the only analysis that lends credence and credibility to alternate motivations for entrepreneurship. Linnanen understands that environmental entrepreneurs are not always driven to the same degree as other entrepreneurs in terms of both “changing the world” and “making money.” His nuanced approach examines drivers and outcomes that affect the creation of environmental startups as well as funding sources, and their eventual success.

Taking the analysis of startup success further, Dr. von Windheim’s Lab-to-Market paper (2014) provides a framework for understanding how startups move from the laboratory to the marketplace. Embedded in this framework is a process (Figure 4), which seeks to maximize the likelihood of success and increase the ability to overcome the traditional obstacles associated with laboratory-originated startups.

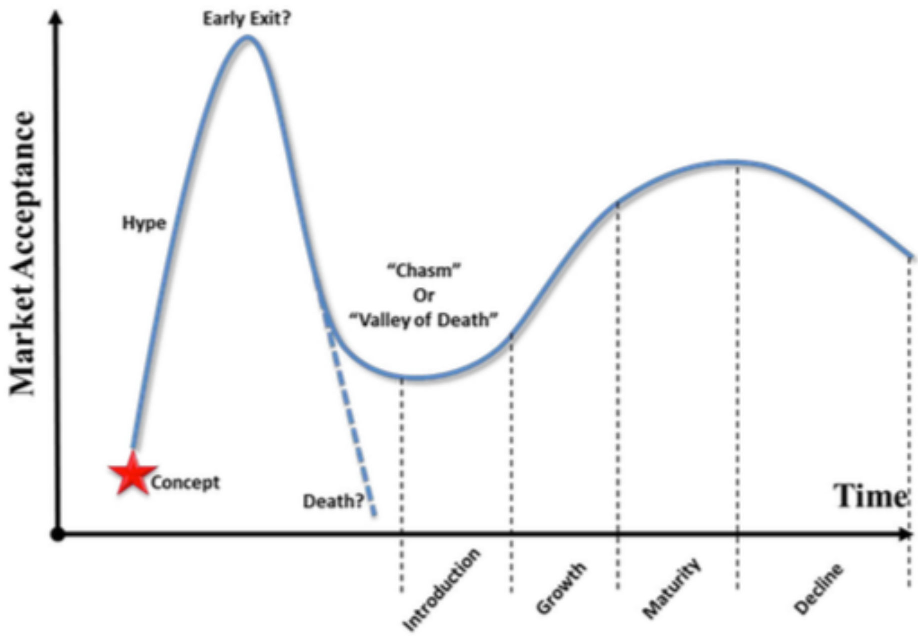
Figure 4 - Lab-to-Market Roadmap



(von Windheim & Myers, 2014)

The framework provides insight on the analysis and tools needed to bridge the gap between traditional university sponsored research, and the venture capital-funded marketplace of established startups (See Figure 5 for the full timeline for the penetration of a new technology into the market).

Figure 5 - Lab-to-Market Timeline



(von Windheim & Myers, 2014)

Dr. von Windheim and Dr. Doyle's Four Forces Framework (2013) is an environmental management and analysis framework derived from Porter's Five Forces analysis for business. The Four Forces Framework develops an analytic tool for evaluating environmental problems and creating management solutions that address the underlying opportunities revealed in the analysis.

Figure 6 - Forces Governing Environmental Metric

(von Windheim & Doyle, 2013)

In this framework, each problem is broken down into an environmental metric and the societal, technical, governmental, and market forces acting upon it. (See Figure 6) By using the Four Forces Framework, environmental opportunities can be uniformly evaluated and ranked based on impact and ability to succeed, and acting upon in a systematic manner.

The entrepreneurial and sustainability literature provides insight into the role entrepreneurs and venture capitalists see sustainability playing in the marketplace. This insight can help to craft and focus the environmental startup, as well as incorporate environmental ideals into the corporate entity and business culture. Creating the right corporate entity with the right environmental ideals will ensure that the startup can properly address its environmental and economic goals while maintaining true to its founding principles.

The Lab-to-Market and Four Forces Frameworks provide the tools with which I analyze, select, and move a startup to market. These build off of and complement the sustainability and entrepreneurship literature, providing a path from the laboratory to the marketplace.

Six Environmental Startup Opportunities at Duke University

In order to find the best opportunity possible for my startup, I searched Duke's available technologies through the Office of Licensing and Ventures, talked with fellow students and faculty, and drew from my own ideas. The ideas that held an initial promise of positive environmental impact, future revenue, and were interesting were gathered and considered.

The top six opportunities identified are addressed below. One idea is my own: the lighthouse rentals for environmental conservation; one idea belongs to a Duke affiliate: macroalgae harvesting; the remaining four are patents held by Duke.

Macroalgae Biomass Harvesting

This company is a coastal oyster farm off the Atlantic Ocean in Virginia, providing oysters to urban markets in Washington, D.C. and Delaware. These oysters naturally work to remove excess nutrients from the bay, which receives excessive agricultural run-off (Matouka & Myers, 2014). The company is interested in expanding their operations to include macroalgae (seaweed) harvesting. By harvesting seaweed, they hope to create a sustainable model for cleaning up hypoxic waterways and produce a natural source of recycled fertilizer.

Lighthouse Rentals

Under The National Historic Lighthouse Preservation Act of 2000, the federal government has started to privatize ownership of historic lighthouses (U.S. General Services Administration, 2013). Since lighthouses are by definition located on the coast, and are often in ecologically sensitive areas, they may lend themselves well to being vehicles for conservation. Since many people harbor a fascination with lighthouses, lighthouses as high-end rental properties offers a revenue stream that may be used to 1.) protect and restore lighthouses that may otherwise fall into disrepair, and 2.) protect and restore ecologically sensitive coastal areas.

Billfish Lure Invisible to Sea Turtles

Dr. Sönke Johnsen has created the design for a billfish lure that is virtually invisible to sea turtles (Duke University Office of Licensing & Ventures, n.d.-a). This would help to reduce the amount of sea turtle bycatch produced each year as a product of billfish fishing.

Lifespan Extension of Mammalian Cells

Dr. Christopher Counter, Associate Professor of Pharmacology and Assistant Professor of Radiation Oncology at Duke University, and Dr. Blaine Armbruster, formerly of Duke University, have created a method to safely extend the lifespan of mammalian cells in a laboratory setting. This provides opportunities for extended and better laboratory research into health and sciences, due to the decreased risk of cancer from this methodology. Patent pending (Duke University Office of Licensing & Ventures, n.d.-b).

Increasing Drought Resistance in Flowering Plants

Researchers at Duke University have discovered the gene responsible for water-stress response in flowering plants. By changing this gene, they believe that they should be able to genetically engineer plants that respond more quickly to water shortages, therefore increasing their drought tolerance (Smith, 2014).

Zylon

Dr. Zachary Reitman and his team at the Duke University Cancer Research Center have discovered an enzyme mutation in brain cancer that was the missing link in a previously theorized pathway to create adipic acid from glucose. Having patented this mutation, Dr. Reitman and his team are working to create adipic acid from glucose, which would allow the production of nylon and other products from cellulosic sugar instead of petroleum.

Five-Metric Opportunity Analysis of Six Opportunities

The opportunities identified for study are first put to a five-metric opportunity analysis. Each opportunity or technology is given a cumulative grade based on five criteria (Each criterion is scored on a scale of 0-5). The criteria are:

1. **Team:** Does this team represent the “best in field” for this particular opportunity?
2. **Technology:** Is the technology novel, interesting, and sufficiently groundbreaking to warrant a startup?
3. **Market:** Does a large enough market for this product exist?
4. **Customers/Revenue:** Are there customers who are currently or are willing to pay for the product? Can this product generate revenue?
5. **Ability to Execute:** Does the team have the skills, knowledge, and resources necessary to successfully launch this opportunity?

Each opportunity is evaluated in detail below and the results are summarized in Table 2.

Macroalgae Biomass Harvesting

Cumulative Score: (11) Strong on Customers, weak on Team and Ability to Execute.

Team: (1) The owner of the company has a background in running small businesses. However, the team does not have the requisite technical experience, academic background, or biology and research skills to move forward.

Technology: (3) Relatively little technology is needed to actually grow and measure macroalgae. However, this opportunity represents an interesting area that is lacking in established, mainstream customers.

Market: (2) There is a demonstrated need for fertilizers and ecosystem services, however, the company has not found a niche. This technology would place them in either small, local markets that have yet to be established, or in direct competition with established chemical companies.

Customer: (5) The company is located on a hypoxic bay, near urban centers that desire ethical, local products, and in the middle of farming communities. There exist multiple constituencies that have or are willing to purchase products developed by the company (to date: oysters) (Matouka & Myers, 2014).

Ability to Execute: (0) While the company has been a successful small company since 2002, there is no indication that they possess the ability to execute on a plan for macroalgae harvesting. They have been researching macroalgae for at least seven years, with no success or substantial external funding to date.

Lighthouse Rentals

Cumulative Score: (9) Strong on Technology and Market, weak on Team and Ability to Execute.

Team: (0) The team has no expertise in property management, hospitality, government properties, or ecological restoration and protection.

Technology: (3) While the idea remains interesting and presents new opportunities, it is complicated from two sides: 1.) companies are converting lighthouses to hotels and hostels already, 2.) purchasing lighthouses from the government would require expertise, connections, substantial legal fees, and a long time horizon.

Market: (3) Hospitality and ecotourism are both huge markets nationally and internationally.

Customer: (2) There are initial customers who have expressed interest in a time-share model across multiple lighthouse locations.

Ability to Execute: (1) Based on the skill deficit of the team, the ability to execute is severely limited.

Billfish Lure Invisible to Sea Turtles

Cumulative Score: (17) Strong on Team, Technology, and Ability to Execute, weak on Market and Customer.

Team: (5) Dr. Sönke Johnsen represents one of the top minds in the field.

Technology: (4) The technology is new and impactful. It is, however, not the only solution.

Market: (2) The market is limited to billfish fisherman world-wide. Additionally, only to those whose government mandates use of alternatives to limited bycatch and those who choose to do so on moral grounds.

Customer: (2) The price potential and market are limited.

Ability to Execute: (4) The team would need to expand into marketing, but is more than capable of turning this into a venture.

Lifespan Extension of Mammalian Cells

Cumulative Score: (11) Weak on Customer and Ability to Execute.

Team: (3) The team is the top of their field. However, they currently lack the necessary expertise to refine the technology into a product that can be marketed.

Technology: (2) The technology is a novel approach to a problem that is widespread in laboratories. However, it has very limited applications in the laboratory.

Market: (3) Due to its limited application, the market for this technology is small but not insignificant.

Customer: (2) The technology has no demonstrated customers. It will struggle for customers, due to the nature of clinical and laboratory testing procedures.

Ability to Execute: (1) The team is geared towards research and development. The ability to launch this as a company is lacking.

Increasing Drought Resistance in Flowering Plants

Cumulative Score: (18) Strong on Customer and Market, weak on Ability to Execute.

Team: (5) The team is among the top of their field in research.

Technology: (3) The technology is novel and has the potential to affect millions of lives and improve food yields, decrease water usage, and be incorporated into standard farming practices.

Market: (5) If feasible, this technology has the potential to penetrate the entire farming industry worldwide.

Customer: (3) Major seed companies, farmers, R&D firms, and the government are all among the entities that are spending money to research and develop similar solutions. While there are currently no paying customers, there should be no shortage upon completion.

Ability to Execute: (2) While the team is among the top of their field, they do not have the expertise to launch a company. However, they are buoyed by the fact that large agricultural companies may be interested in quickly bringing this technology in-house.

Zylon

Cumulative Score: (21) Strong on Market and Technology, weak on Customer.

Team: (4) The Zylon team is comprised of M.D./Ph.D. candidates who are the top in their field of brain cancer research. They are familiar with enzyme reactions, and are competent at most of the science behind the adipic acid production process.

Technology: (5) Adipic acid production from alternative feedstocks is currently being researched by no less than 3 startups backed by major firms (Grand View Research, 2014; IHS, 2012b). The ability to produce nylon from cellulosic sugar would be a major breakthrough.

Market: (5) The market for adipic acid is over $6 Billion worldwide (MarketsandMarkets, 2014).

Customer: (3) While traditional adipic acid manufacturers may be hesitant to switch to a new production method, there are entities investing in research. This indicates a willingness to pay for and use the end product.

Ability to Execute: (4) The team has demonstrated the ability to develop, cultivate, and test the technology. They have secured a Technology Enhancement Grant (TEG) from the North Carolina Biotechnology Center (NCBC), created investor pitches, and held exploratory meetings.

Table 2 – Five Metric Opportunity Analysis Chart Results

	Lighthouses	Macroalgae	Billfish Lure	Mammalian Cells	Drought Resistance	Zylon
Team	0	1	5	3	5	4
Technology	3	3	5	2	3	5
Market	3	2	2	3	5	5
Customer	2	5	2	2	3	3
Ability to Execute	1	0	4	1	2	4
Cumulative	9	11	17	11	18	21

Detailed Opportunity Analysis of Top Three Opportunities

The top three opportunities were selected based on scores from the five-metric opportunity analysis. This scoring, however, is simply an effective down-selection process if many opportunities are under review. It does not get as nuanced as is necessary once fewer opportunities are available, nor does it address important factors such as the potential environmental impact.

The three opportunities that scores highest on the opportunity analysis are: Zylon; increasing drought resistance in flowering plants; and the billfish lure that is invisible to sea turtles. In order to choose one, their scores are set aside and a more detailed evaluation is carried out.

Zylon

Current adipic acid production methods create adipic acid from benzene, a petroleum derivative. Adipic acid is then used to create 6,6-nylon, as a food additive, for medical equipment, and as part of pharmaceuticals (IHS, 2012b). The worldwide adipic acid market is over $6 Billion, and is expected to grow at 3-5% annually (IHS, 2012a).

The discovery of this particular enzyme mutation in brain cancer, the missing link in a pathway from glucose to adipic acid as posited by Dr. Buckel, represents one of the most theoretically feasible methods for switching adipic acid production from its petroleum feedstock to a renewable feedstock (Parthasarathy, Pierik, Kahnt, Zelder, & Buckel, 2011).

Industry analysis indicates that adipic acid production from a sugar feedstock would have a financial advantage based on lower feedstock costs, production costs, and overhead costs (Grand View Research, 2014).

Dr. Reitman has left Duke University upon the completion of his degrees, but remains involved and has handed over day-to-day control of the lab trials to Bill Diplas, an M.D./Ph.D. student in the same lab. Mr. Diplas continues to operate under the NCBC TEG procured by Dr. Reitman.

Increasing Drought Resistance in Flowering Plants

"Duke University researchers have identified the gene in plants that encodes a protein in the cell membrane, that senses changes in water availability and adjusts the plant's water conservation accordingly" (Smith, 2014).

Dr. Zhen-Ming Pei, one of the researchers and an associate professor of biology at Duke, claims that the gene acts like a thermostat. When it senses a water shortage, it increases Ca^{+} within cells, which acts as a coping mechanism for the drought (Yuan et al., 2014).

This technology could help farmers worldwide deal with the looming droughts presented by climate change. However, before the technology can be applied, further research is necessary. Additionally, this represents only one of many ways in which plants are placed under stress in drought conditions.

Billfish Lure Invisible to Sea Turtles

Dr. Johnsen has invented and patented a billfish lure that is effectively invisible to sea turtles when in use. This is of importance, since there is a high level of incidental capture of sea turtles in pelagic longline fisheries. Most of the interactions between fishing lines and sea turtles occur with lines for swordfish, mahi mahi, and surface-feeding tunas (Brill & Swimmer, 2006).

All five species of sea turtles living in the Pacific Ocean are either listed as threatened or endangered under the U.S. Endangered Species Act of 1973 (Brill & Swimmer, 2006). Bycatch fatalities play a major role in the deaths of these protected animals, and thus research and solutions are of paramount importance.

Dr. Johnson's billfish lure may be a viable technology and may ultimately play a major role in helping prevent sea turtle bycatch, but the market opportunity remains low, making it a poor startup candidate.

Selection

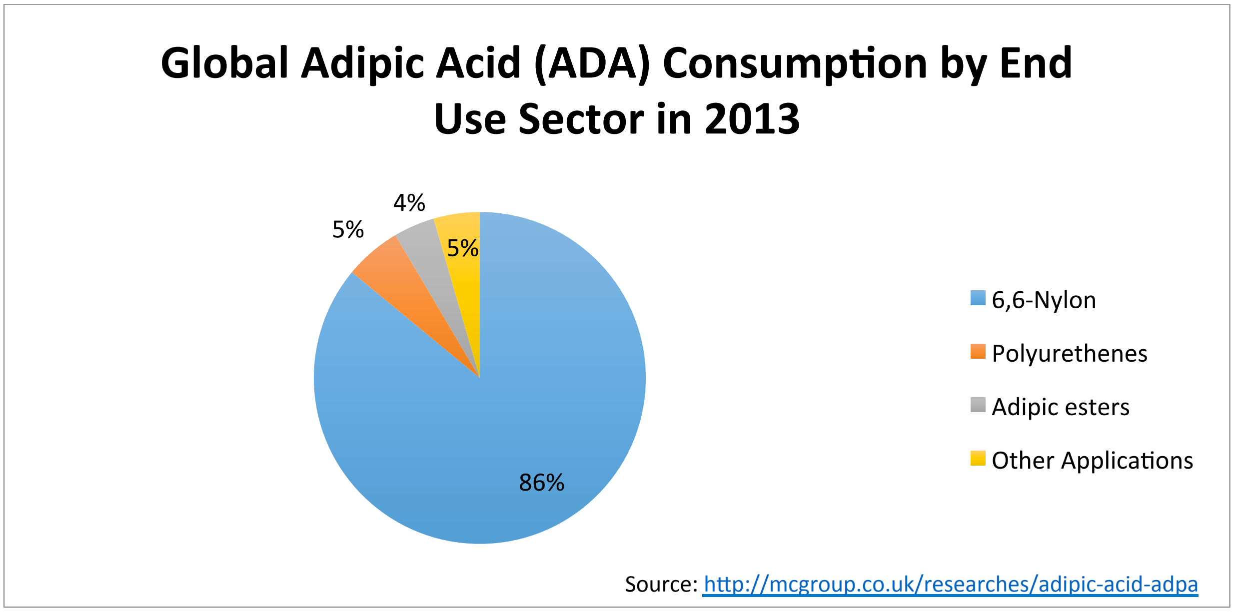
Based on potential environmental impact, scalability of the idea, team, and addressable market size, Zylon appears to be the best environmental startup opportunity presented. Zylon has the potential to be worth billions of dollars, is at the point in its development where it can be moved out of the university, and is backed by incredible scientists.

The billfish lure falls short based on potential market size and, while it addresses an important and pressing environmental problem, comes nowhere near the impact of potentially eliminating nitrous oxide emissions from conventional adipic acid production. Similarly, increasing drought resistance in flowering plants is a potentially world-changing development that could help to avert global food crises and deal with looming water shortages, but is not ready to move beyond the lab.

Four Forces Analysis of Zylon

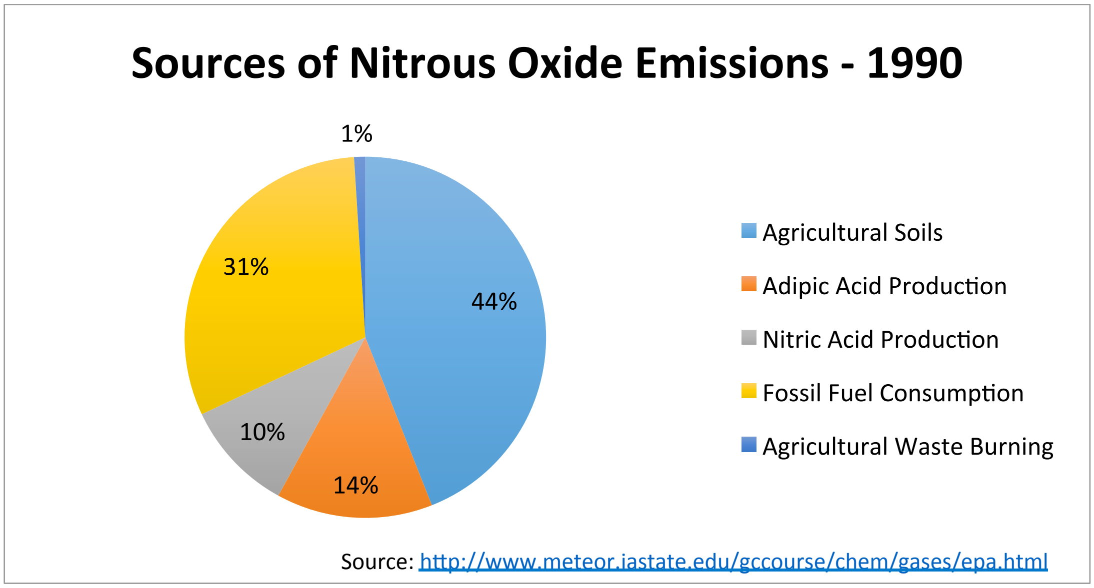
Nylon is a ubiquitous product: it is used in everything from automobile parts to clothing to medical devices. However, the precursor to 6,6-nylon is adipic acid – a substance currently produced primarily from benzene and cyclohexane, which are petroleum derivatives.

Figure 7 - Global Adipic Acid Consumption by End Use Sector in 2013



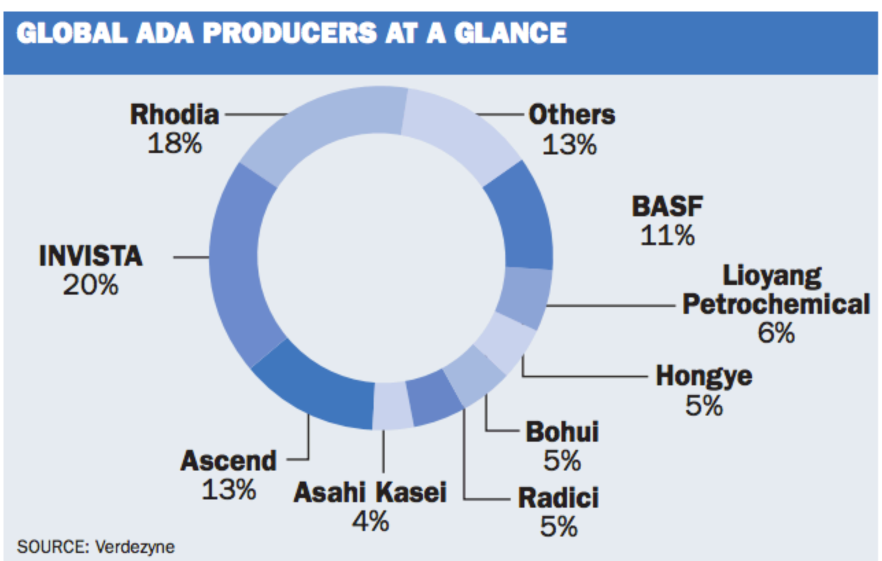
Using petroleum derivatives as a feedstock for adipic acid creates a significant CO_2 footprint and produces N_2O (Figure 8), a potent molecule with a global warming potential 300 times that of CO_2 (U.S. Environmental Protection Agency, 2014). Switching to a renewable, non-petroleum feedstock with a new production process has the potential to reduce or eliminate these environmental impacts while at the same time also possibly reducing cost.

Figure 8 - Sources of Nitrous Oxide Emissions - 1990



Global adipic acid demand is estimated at 2.3 million metric tons in 2012 and growing at 3-5% annually (IHS, 2012b). Global production is valued at over $6 Billion, and is concentrated among a handful of companies, many of whom are located in China. This is a trend that is expected to continue as companies vertically integrate nylon and adipic acid production and move production to China (IHS, 2012a).

Figure 9 - Global Adipic Acid Producers



Environmental Quality Metric: Renewable, non-petroleum feedstock.[1]

> **Governance:** Governments worldwide currently invest in research into alternative methods of adipic acid production; however, oil subsidies and a lack of environmental regulations prevent mass industry shifts.
>
> **Behavior:** Consumers want cheap plastics and nylon products, and thus resist changes that would increase costs. However, a growing green consumer movement promises support for products from alternative methods.
>
> **Markets and Economics:** Since adipic acid is the same regardless of production technique, end-users are unlikely to use a more expensive alternative. However, should Zylon prove feasible, it will have allure as a cheaper alternative.
>
> **Science and Technology:** There are proven ways to produce adipic acid from renewable, non-petroleum feedstocks, but none of them have proven to be financially viable. Nonetheless, companies continue to invest heavily in R&D and startups with bio-based adipic acid production technologies.

Behavior and economics are two of the weakest forces identified in this analysis, showing the potential for the best return on investment, but also allowing the easiest access. By targeting behavior and economics, consumers and companies will fund and drive the final research and development needed to create competitive bio-based adipic acid production techniques. Corporations and government grants can subsidize research, invest, and provide backing until such time as the technology is viable.

Customers can create the demand necessary to drive the break-even point on new technologies down until they are financially feasible. This can either come through pressuring traditional companies to use a renewable feedstock instead of petroleum or through the creation of niche markets that command a premium and pass this revenue down stream to pay the higher costs of production. Given the status of the technology, and the very significant investment that would be required to take Zylon mainstream, it would appear that targeting the growing

[1] See Figure 12 and Figure 13 in the Appendix

demand for green products and focusing on small volume, niche applications may be a way to move Zylon into the market at a pace that is consistent with the development time-scale of the technology.

It is very likely that renewable, non-petroleum bio-based adipic acid production will happen. The key is implementing a strategy that takes advantage of both the economics and societal behavior to hasten financial feasibility and allow the technology to develop at a faster pace.

The Business Case for Zylon

Zylon is a breakthrough technology to create nylon from non-petroleum sources (See Figure 10 and Figure 11 in the appendix). Its peer-reviewed process provides Zylon the technical capability to produce adipic acid, the precursor to nylon and other products, from glucose and has it poised to enter the $6.1 billion adipic acid market. The company is comprised of professional degree students from Duke University and is backed by researchers from the prestigious Duke Cancer Research Center with the ultimate goal of commercializing patented research from Duke University.

Zylon will license a patent from Duke University by vehicle of an option letter to license the patent exclusively use on a mutated enzyme-biocatalyst that is the missing link in a theorized pathway for creating adipic acid from glucose instead of petroleum, specifically benzene. The resulting adipic acid is chemically identical to adipic acid from traditional reactions, costs less due to a cheaper feedstock, and uses a balanced production process. The reaction is more environmentally friendly, less wasteful, and reduces human health risks associated with handling benzene.

For a licensing fee, current adipic acid producers will be able to use Zylon's mutated enzyme in their own factories to create a chemically identical adipic acid. There will be an upfront cost for new or retrofitted equipment that will be more than offset by lower operating costs, cheaper feedstock prices, and new sales generated by a differentiated "green" product (Grand View Research, 2014). This will ensure a smooth entry into the traditional adipic acid market and fulfill demand for those looking to produce nylon with a lower carbon and environmental footprint.

Currently, Zylon is an early stage startup in the technology validation process. Lab trials are underway at the Duke Cancer Research Center and led by M.D./Ph.D. candidate Bill Diplas, who has worked in conjunction with Dr. Zach Reitman, the M.D./Ph.D. who first discovered the enzyme mutation. This research is funded by a grant from the North Carolina Biotechnology Center, and will produce adipic acid in the lab by late 2015.

Once the glucose-based adipic acid has successfully been produced in the lab, Zylon is looking to raise grant funding or funding from partners in order to complete the lab trial and proof of concept in 8 months. Following successful completion of the lab trial, Zylon will look to raise $1 million dollars in venture funding to refine the production process, line up like minded producers, and begin full-scale test production at a contracted lab.

Zylon's current competition includes Verdezyne and Rennovia. Both companies have already raised significant amounts of capital and are in later research phases. However, neither has been able to successfully enter the market at significant scale. If lab trials are successful, Zylon will be catapulted in front of these two companies who have had years to get to market.

There is inherent risk in an early stage startup whose valuable technology is still in the validation stage; the pathway may not function to perfection at this time. On the production side, the process may not lend itself to scaling. If that is the case, additional research funding and time may be required to fine-tune the process, which could jeopardize Zylon's potential place in the market. However, we are confident in our team and technology and believe that Zylon will have a proof of concept in eight months.

Next Steps

Zylon has neither been incorporated nor launched as a funded startup. However, neither of these should be considered a failure on behalf of the Zylon technology, the frameworks utilized, or the resources available at Duke University and the Nicholas School for startups. Zylon has reached the “Valley of Death” presented in the Lab-to-Market framework (von Windheim & Myers, 2014), and is well positioned to attempt to cross the gap.

The courses provided by the Environmental Innovation & Entrepreneurship Certificate track, as well as the interest and support offered by the Nicholas School has given Zylon a significant advantage when competing against other fledgling startups. Zylon was given the tools necessary to create materials that investors want to see, and gain hands-on experience crafting lean businesses that successfully incorporate environmental metrics into the corporate entity itself.

Next Steps:

Demonstrate the improved economics of Zylon.

Seek out niche markets where green nylon will be prized.

Move Zylon out of the university.

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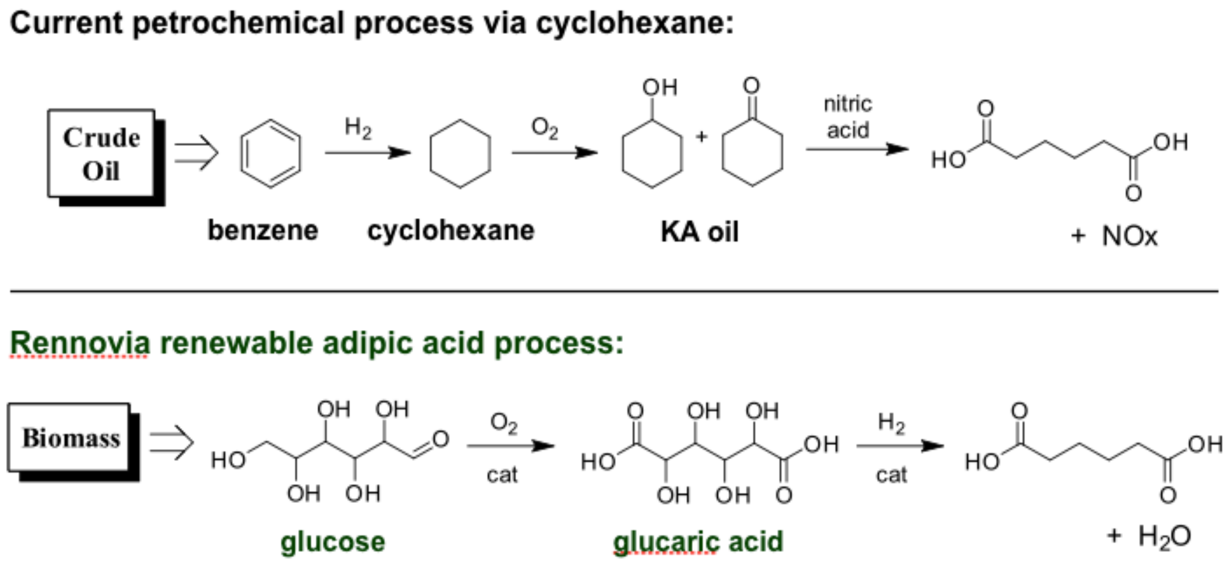
Appendix

Figure 10 - Adipic Acid Production Cycle



• Broad IP filed
• Preliminary cost estimates below cash-cost of cyclohexane process

Source: http://www.icis.com/blogs/green-chemicals/2010/09/introducing-rennovia/

Figure 11 - Zylon's Pathway with Enzyme Mutation

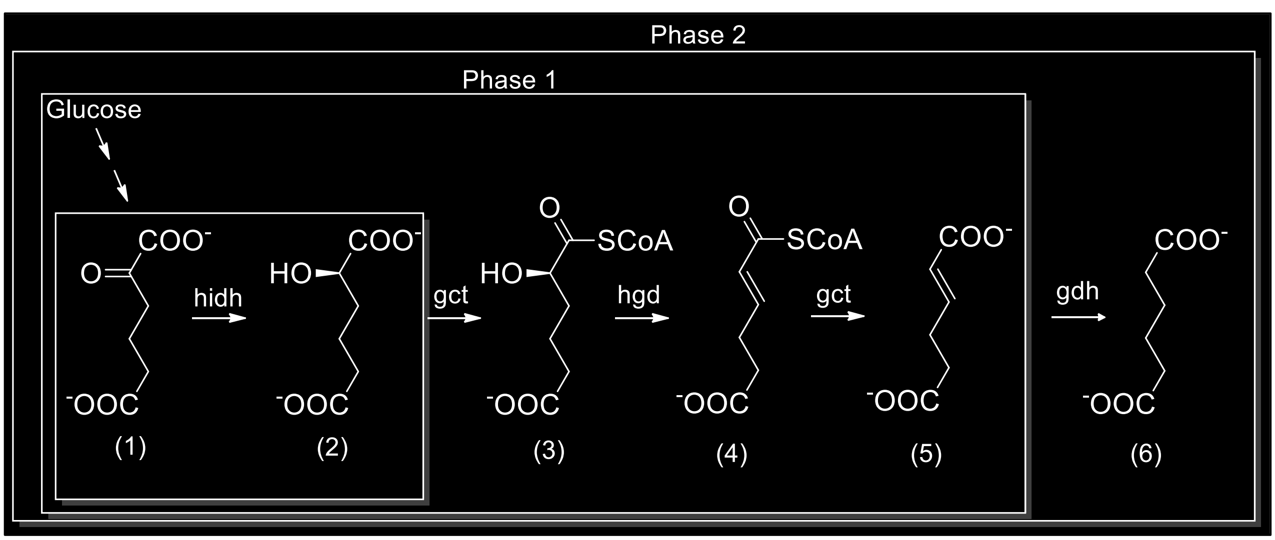


Figure 12 - Zylon Four Forces Analysis Chart

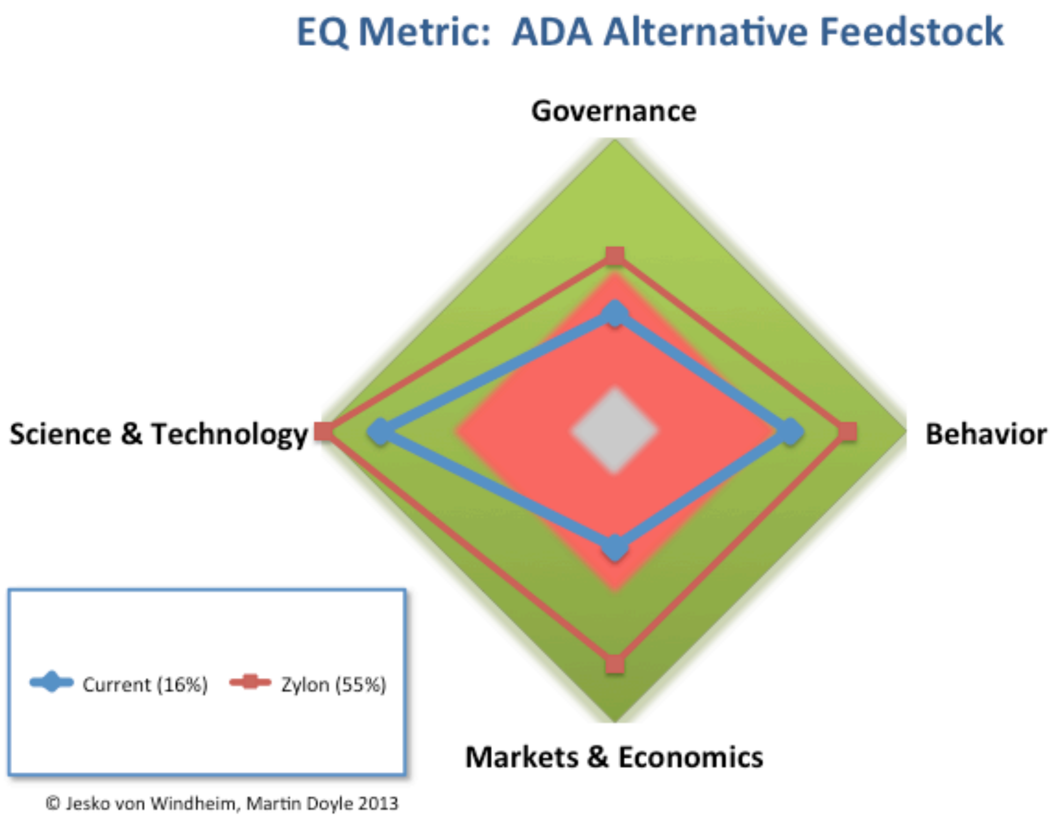


Figure 13 - Zylon Four Forces

Governance: Governments worldwide currently invest in research into alternative methods of adipic acid production. Government backed loan programs for renewable energy, advanced research, sustainable materials, and grants for environmental entrepreneurship are abundant. It should be possible to either use existing government programs for adipic acid research and development or solicit new government backing on the grounds of job creation, advanced research opportunities, and independence from foreign oil.

However, oil subsidies and a lack of environmental regulations prevent mass industry shifts. By providing subsidies for oil exploration, cheap drilling permits for federal lands, and tax breaks for energy companies, government policies currently undermine the competitiveness of alternative adipic acid production methods. If adipic acid producers paid the true costs of petroleum, renewable feedstock methods would most likely become immediately feasible.

Behavior: Consumers want cheap plastics and nylon products, and thus resist changes that would increase costs. This is a staple of the U.S. economy, which is exemplified by such sites as half.com, amazon.com, ebay.com, and 6pm.com, where consumers can purchase products at steep discounts. Research by the Boston Consulting Group (BCG) indicates that typical consumers are willing to pay an average premium of 10% for products with the "Made in America" label (Sirkin, Zinser, & Manfred, 2013). However, 10% would not cover the price difference between traditional and renewable adipic acid production, were it available today.

A growing conscientious consumer movement promises support for products considered higher quality or that supports a social goal. From Tom's to Burt's Bees to Annie's, consumers purchase from companies that donate shoes, use all natural ingredients, or simply make everything from bee products. Research from Mintel (2013) shows that consumers already make "green" decisions when shopping. A movement like this could be harnessed to provide market leverage for an "environmentally-friendly" nylon.

Markets and Economics: Since adipic acid is the same regardless of production technique, end-users are unlikely to use a more expensive alternative. The higher costs of current alternative feedstock adipic acid production would be passed on to the end-product producers and ultimately, consumers. Because of the degree of separation, and barring a concerted effort to market products as “Made from renewable feedstock,” the cost would simply make products uncompetitive in today’s market. However, a cheaper production alternative could make headway in high-use markets, where the consumer can gain the cost savings of the production process.

Science and Technology: There are proven ways to produce adipic acid from renewable, non-petroleum feedstocks, but none of them have proven to be financially viable. Both Rennovia and Verdezyne, the two most advanced bio-based adipic acid producers on the market, have significant challenges ahead of them that include technology enhancement and scalability (IHS, 2012b).

Nonetheless, companies continue to invest heavily in R&D and startups with bio-based adipic acid production technologies. With the enormous number of pathways possible from different sugars (glucose, sucrose, fructose) to adipic acid, and the various methods available (catalytic, enzymatic), the science and technology behind alternative adipic acid production has only begun. All of the methods and pathways are technically viable. The most successful company will be the one that chooses and optimizes the most efficient and fiscally feasible pathway.